A UHV X-ray Beam Positioning System, Using a quadrant PIN Photodiode Array

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1 Introduction

Experiments at Advanced Photon Source often require a very stable beam. While a perfectly stable beam is impossible because of a multitude of small factors resulting in the instability, being able to know the position of the X-ray beam while conducting experiments at synchrotron radiation sources is very valuable information. At the APS, the source point typically will move with a standard deviation of 4 μm and 2 μm in the horizontal and vertical direction respectively. Furthermore, the typical x-ray beam pointing stability is on the order of 0.1 μrad. Thus for an experiment 60 m from the source, beam motion on the order of 10 μm are to be expected during normal operation. Using the x-ray fluorescence from a metal foil and a simple quadrant diode array, beam resolution on the order of microns can be obtained[1].

For relatively low cost, a vacuum-compatible beam position monitor can be created using an array of PIN diodes, and a metal foil, usually Titanium, or Chromium. The X-ray beam hits the metal foil causing a spherical and isotropic fluorescence. Using a backscattering geometry, the PIN diodes will have a current output proportional to the flux of the fluorescence hitting them. This is directly dependent on the solid angle with which the diode sits, which determines the relative change in beam position due to the change in fluorescence flux hitting the photodiodes.

2 Equipment

In order to make the PIN diode detector vacuum accessible, thought had to be given to what equipment to use. The housing that holds the PIN diode array and the Cr foil was a major concern. Plastics would be rather dirty in a vacuum situation, instead a material called G-10, a fiberglass composite material was used. This material is known to work well in a UHV environment, and is relatively easy to machine. When considering the construction of the G-10 array and foil holder, some special care must be taken to insure that the wiring of the diode has adequate room. This can be accomplished by milling two simple grooves, as shown by figure 1.

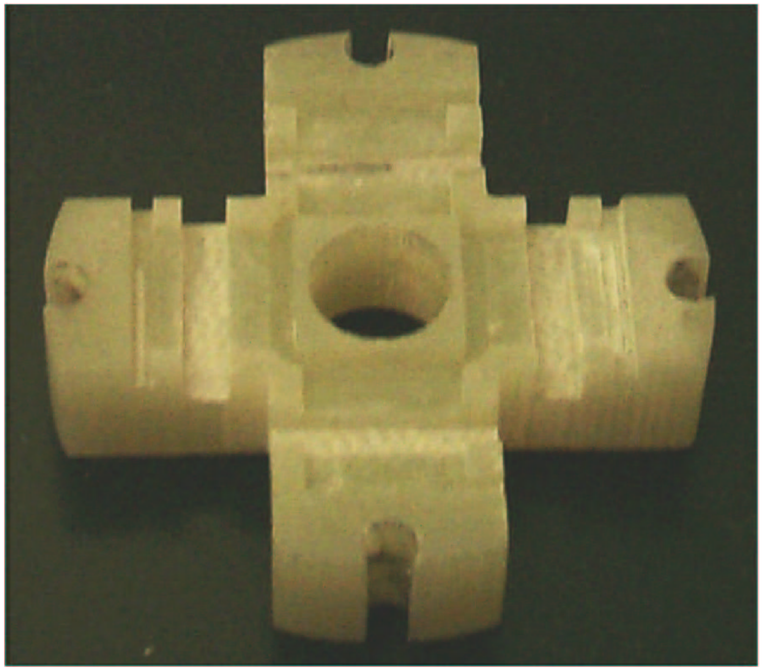

Figure 1: The G-10 quadrant array diode holder.

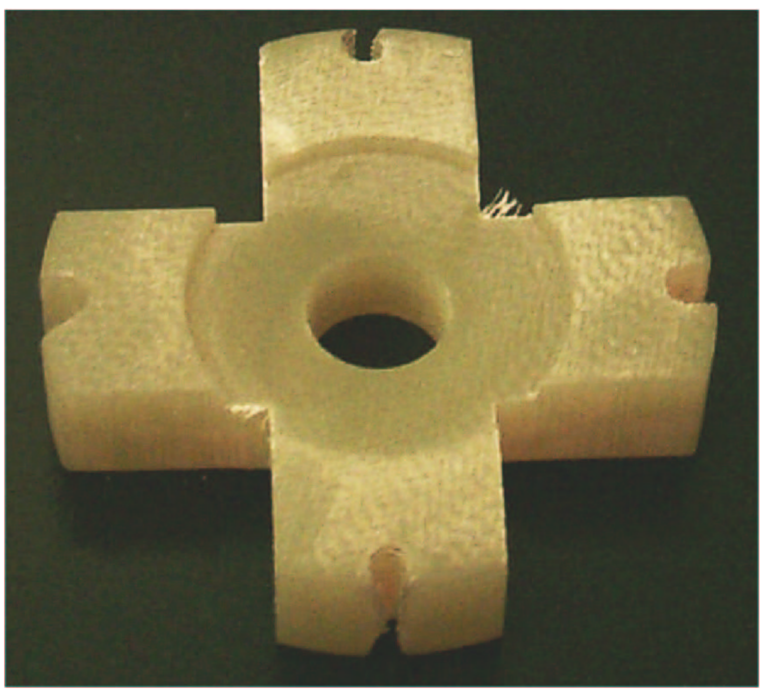

Figure 2: The G-10 foil holder.

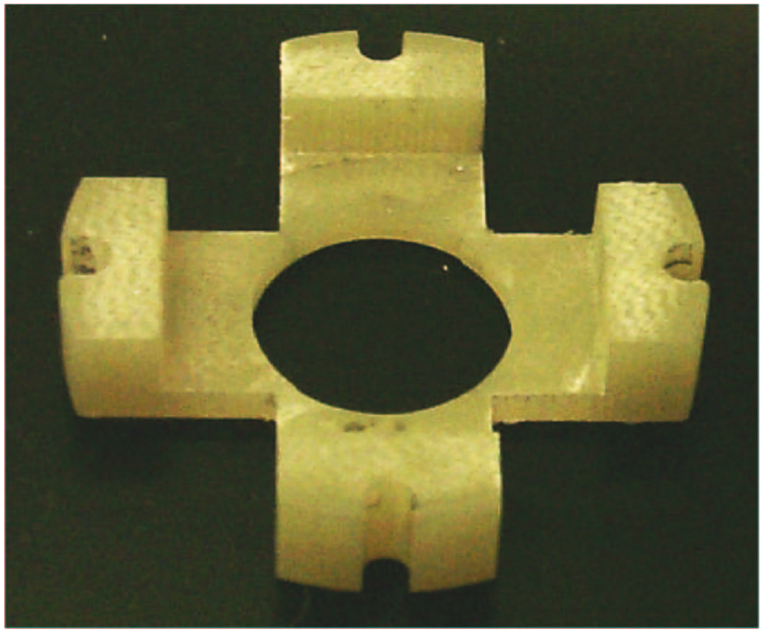

Figure 3: The G-10 spacer between diode array and Cr foil.

The groove for the bottom ground wire needs to be deeper and wider to assist in clearance. Also, the alcove where the diodes sit must be made deep enough to not only clear the top wire, but also to allow the diode to sit perfectly flat adding to the overall effectiveness of the device. A Tantalum backing had to be made to block any stray scattered x-rays. It is attached to the upstream side of the diode array. The Cr foil is 0.5 μm thick on an 11.1 mm inner diameter washer, and can be obtained from ACF metals in Tucson, AZ. Chromium is an optimal choice and creates a higher sensitivity than Ti does. The current Cr produces at 8keV was 2.7 μA and at 12keV produces 0.42 μA. The current Ti produces at 8keV was 0.88 μA and at 12keV produces 0.14μA. The currents directly relate to the sensitivity.[1] The diodes are PIN diodes model S100VL and can be obtained from UDT Sensors, Inc. in Hawthorne, CA. A 4-way cross vacuum piece is used to allow the beam to travel through, have an attachment to evacuate the chamber, and to allow for an electrical feed-through. For further sophistication, a 5-way cross could be used to have a mechanical device for removing the foil to allow the beam uninhibited passage.

3 Theory

It can be shown that the current of this device is given by (1).

$$i = \alpha \left(\frac{Y(1-T)\Phi}{4\pi} \frac{E_{Cr}}{E_i} e \right) \int_{\Omega} d\Omega \tag{1}$$

Here;

$$\int_\Omega d\Omega = \int_{-\phi}^{\phi}\int_{\theta_1}^{\theta_2} \sin d\theta d\phi = \Big[\phi\Big]_{-\phi}^{\phi}\Big[-\cos\theta\Big]_{\theta_1}^{\theta_2} \tag{2}$$

In equation (1), $\alpha = 100\%$ is assumed for the quantum efficiency of the detectors, $Y = 0.28$ is the fluorescence yield for Cr, $T = 95.5\%$ is the transmission of the foil at 10keV, $\Phi = 1.0 * 10^{13}$photons/sec is the flux of the x-ray beam, $E_{Cr} = 5415$eV is the Cr Kα energy, $E_i = 3.55$eV is the binding pair energy of Si , and $e = 1.6 * 10^{-19}$C is the charge of the electron.

$$R = \frac{i_1 - i_2}{i_1 + i_2} = \frac{\cos\theta_1 - \cos\theta_2 - \cos\theta_3 + \cos\theta_4}{\cos\theta_1 - \cos\theta_2 + \cos\theta_3 - \cos\theta_4} = \tag{3}$$

$$\frac{\frac{Y_d-\Delta y+L}{\sqrt{R_d^2+(Y_d-\Delta y+L)^2}} - \frac{Y_d-\Delta y}{\sqrt{R_d^2+(Y_d-\Delta y)^2}} - \frac{-(Y_d+\Delta y)}{\sqrt{R_d^2+(Y_d+\Delta y)^2}} + \frac{-(Y_d+\Delta y+L)}{\sqrt{R_d^2+(Y_d+\Delta y+L)^2}}}{\frac{Y_d-\Delta y+L}{\sqrt{R_d^2+(Y_d-\Delta y+L)^2}} - \frac{Y_d-\Delta y}{\sqrt{R_d^2+(Y_d-\Delta y)^2}} + \frac{-(Y_d+\Delta y)}{\sqrt{R_d^2+(Y_d+\Delta y)^2}} - \frac{-(Y_d+\Delta y+L)}{\sqrt{R_d^2+(Y_d+\Delta y+L)^2}}} \tag{4}$$

$$\lim_{\Delta y\to 0} \frac{R(\Delta y) - R(0)}{\Delta y} \simeq \frac{dR}{d\Delta y} = 0.1627 \tag{5}$$

The angles are measured with respect to the plane of the foil, and are dependent on the dimensions of the distances from the foil, and the center line. This calculation is done in a 2-d system, using the y-axis. X-axis calculations are identical. Where $R_d = 8.89$mm is the distance from foil to diodes, $Y_d = 6.707$mm is the distance from center line to bottom of the photodiode, $L = 9.7$mm is the length of the photodiode, and Δy is the change in beam position. The ratio of the difference of the current, and the sum of the current (3,4) is how the position of the beam is determined. As the beam moves closer to certain photodiodes, the current increases, thus changing the sum-difference. The derivative of the ratio is what determines the overall sensitivity of the device. Since the ratio is dependent on Δy the sensitivity also depends on Δy. The sensitivity of the device at $\Delta y \ll 1$ is approximately 0.1627 seen in (5). Figure 4 shows this slope as the straight line. The dashed line in the center is where the sensitivity is within 1% of the 0.1627 line, and the outer dashed line extending to the graph show the 10% range of sensitivity.

By factoring out all the constants, it is shown that (5) is only dependent on the solid angle of the diodes. Therefore the dimensions of the diode array is the true determining factor in the sensitivity of the device. As you bring the photodiodes closer to the foil, at a certain point the angle between the photodiodes area vector and the fluorescence vector approach a right angle.The function of the current with respect to R_d peaks at $R_d = 7.921$mm with $6.903 * 10^{-7}$ A, as shown in figure 5. The value chosen for this device was $R_d = 8.89$ mm. This was chosen because the slope from $R_d = 7.921$ mm to zero is much steeper than the slope from $R_d = 7.921$ mm back. Thus giving a little more distance insures good current, where is you make it slightly too little distance, you can stand to loose substantial current.

References

[1] R. Alkire et al... J. Synch. Rad. (2000).

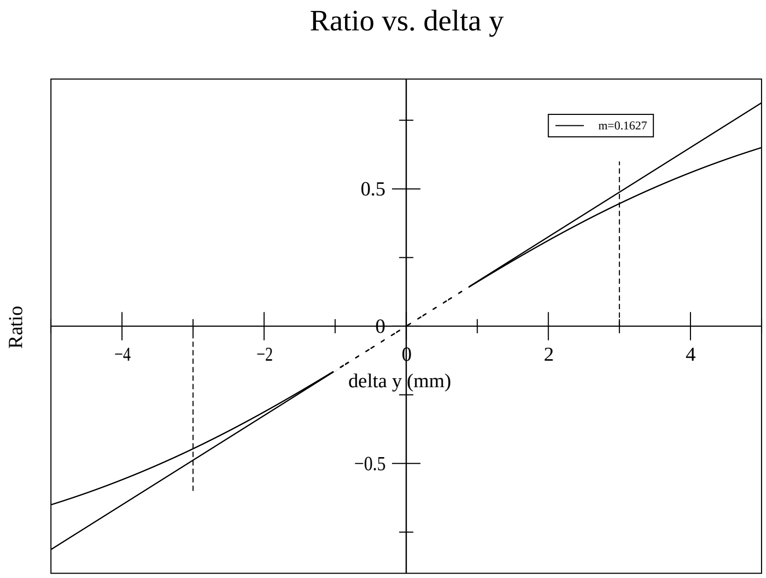

Figure 4: The calibration ratio vs Δy, where dashed lines represent $\pm 1\%$ and ± 10 % deviation.

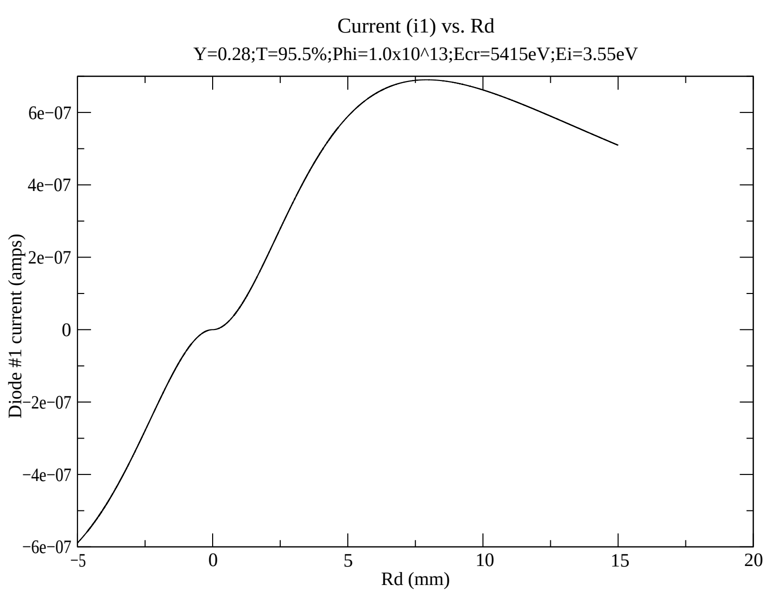

Figure 5: The current vs Rd.

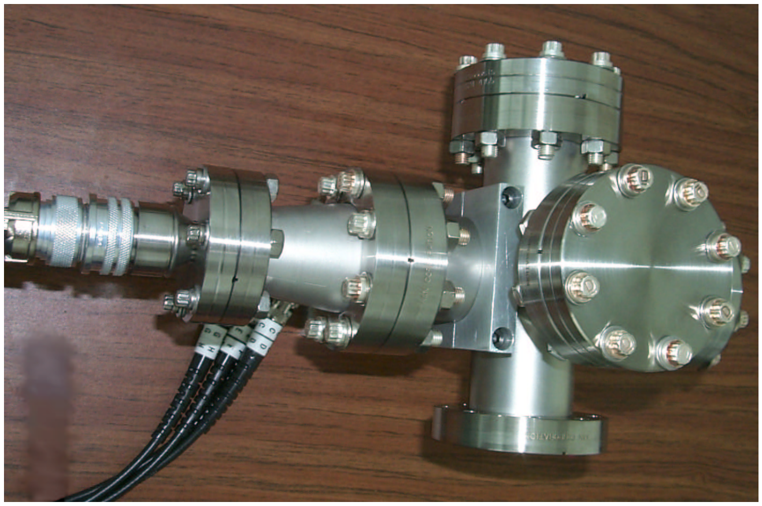

Figure 6: Device after assembly (front face).

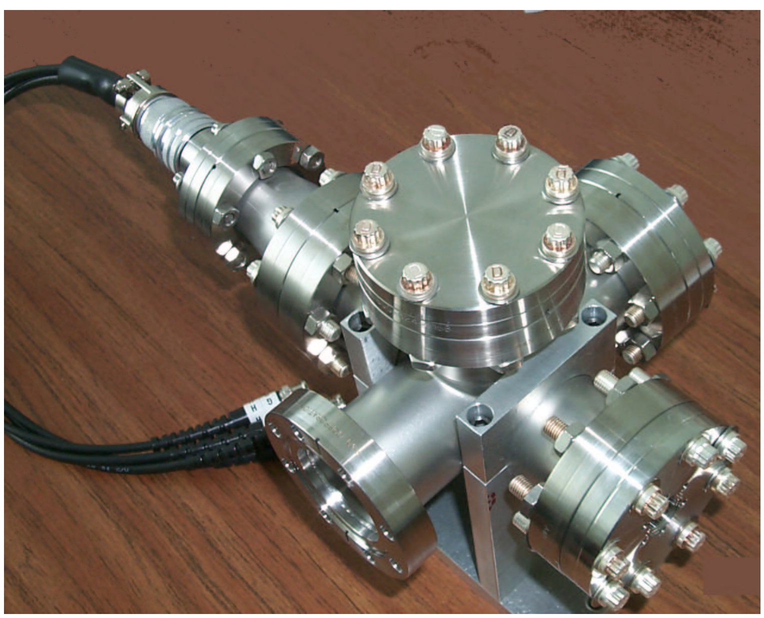

Figure 7: Device after assembly (front face).

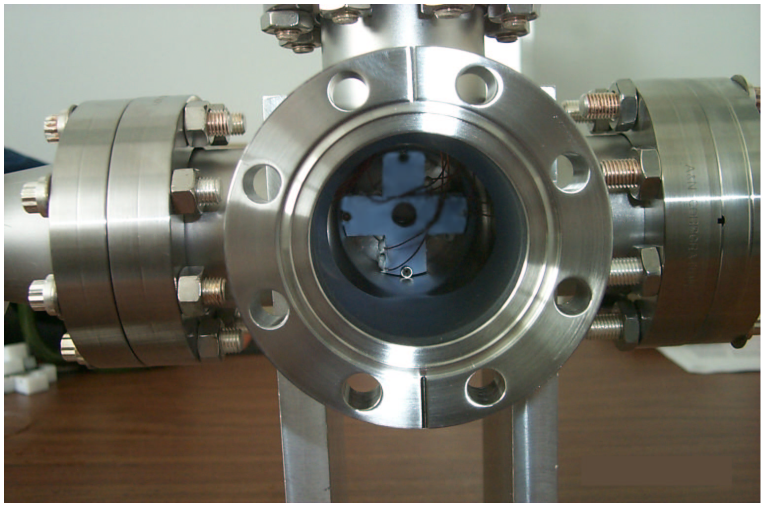

Figure 8: Device after assembly (inside view).

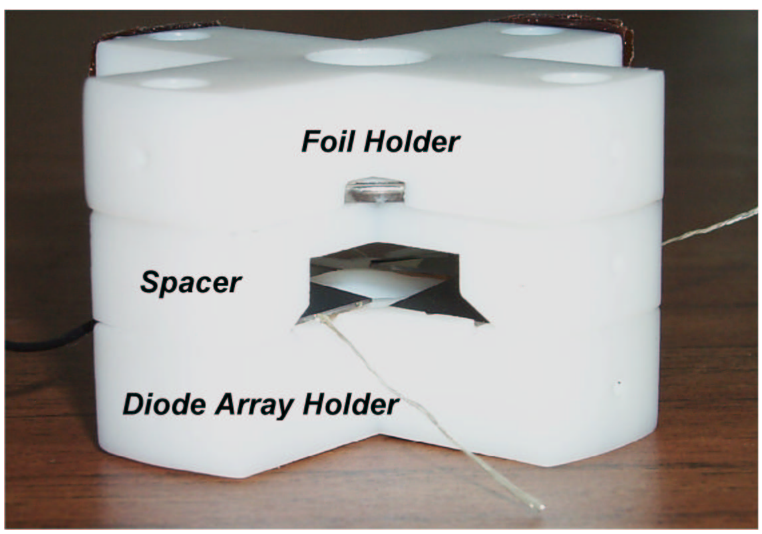

Figure 9: Stack of pieces from previous device, made of Teflon rather than G-10, and not made to fit into UHV.

Description	Manufacturer	Part number	Price
Cr Foil	ACF Metals	N/A	\$290.00
Photodiodes	UDT Sensors	S100VL	\$43.00
5-Way Cross	A&N Corp.	338-200-5X	\$365.00
$3\frac{3}{8}'' \rightarrow 2\frac{3}{4}''$ Conical Reducer	A&N	338x275-CR	\$105.00
$3\frac{3}{8}'' \rightarrow 1\frac{1}{3}''$ Reducing Flange	Kurt J. Lesker	RF337X133	\$60.00
$3\frac{3}{8}'' \rightarrow 6''$ Reducing Flange	Kurt J. Lesker	CRN337X275	\$110.00
10 Pin Electrical Feedthrough	Kurt J. Lesker	IFTA6105103	\$380.00
BeCu crimp/solder connectors	Kurt J. Lesker	FTAPC062	\$50.00
Ta Plate	Goodfellow	TA000490	\$118.50
Vertical slide	Velmex	MA4012P40-S6	\$697.00
Horizontal slide	Velmex	MA6012P40-S6	\$875.00
Slide Motors	Velmex	MO62-LS553E	\$330.00
Vert./Horiz. Adapter Plate	Velmex	A6001X7	\$133.00
6-32 1.5$''$ vented screws	U-C Components	C-642	\$14.44
UNISTRUT Assembly	McMaster-Carr	various	\$154.72
BNC cables	Storeroom	2 2249-C-36	\$18.82

Table 1: BPM Component list